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Evaluation of Alumina Extraction From Coal Waste: Composition and Availability

By Roy T. Sorensen and John L. Schaller

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

Btu	British thermal unit	pct	percent
Btu/lb	British thermal unit per pound	µm	micrometer
° C	degree Celsius	tpy	ton per year
lb	pound	yd^3	cubic yard

EVALUATION OF ALUMINA EXTRACTION FROM COAL WASTE: COMPOSITION AND AVAILABILITY

By Roy T. Sorensen[1] and John L. Schaller[2]

ABSTRACT

This Bureau of Mines report presents the results of a study to rank technologies for extraction of alumina from bottom ash and coal shale. The available literature on composition and availability of coal waste was reviewed, and papers pertinent to alumina extraction are referenced.

Types of coal waste were categorized by method of waste generation, coal content (heating value), location, coal type (ash nomenclature), and alkaline earth content. The differences and similarities among the categories of coal waste are summarized as to factors that may affect aluminum extraction, especially factors concerning chemical composition, current production, storage problems, and accumulated tonnage. Data available on physical characteristics and mineralogy did not correlate well with the individual categories of coal waste, and discussion on these two aspects is limited to the differences between coal ash and coal shale.

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INTRODUCTION

About 80 million tons of coal shale, as coal treatment plant or mine waste, is being produced annually in the United States and about 3 billion tons has accumulated (15).[3] Total ash production is about 70 million tons annually, and about 500 million tons has been accumulated. About 20 pct of the coal ash is bottom ash or boiler slag.

Ash makes up from 3 to 30 pct of the coal. Fly ash is the predominant form of ash produced in the United States and ranges from 10 to 90 pct of the ash. The remainder is a coarser fraction, called boiler slag when it is slagged in the burners and dropped into water filled hoppers. When the coarse ash falls through burner grates and is collected dry, it is called bottom ash. The relative distribution between coarse ash and fly ash for different types of firing is shown in table 1 (35). The distribution of the various types of accumulated anthracite wastes are shown in table 2. The size differences between bottom ash and fly ash are illustrated in figure 1 (69). The fly ash particles range from 0.5 to 100 µm. Glass comprises 50 to 90 pct of the ash weight. Other components are spinels including magnetite, hematite, carbon ranging from elemental carbon to unburned coal, mullite, and quartz. Alumina is contained in both the mullite and the glass fraction. Other alumina-containing minerals include metakaolin, muscovite, and spinel type especially when the coal combustion is carried out at lower temperatures. Metals are leachable to some extent from fly ash, but less from bottom ash. Thus, fly ash is of enviromental concern. However, high-carbon-content ashes are not considered a combustion hazard. Bottom ash is usually denser and, according to Professor J. Leonard, University of Kentucky, can contain more iron.

[3]Underlined numbers in parentheses refer to items in the list of references at the end of this report.

TABLE 1. - Comparison of typical distribution between coarse ash and fly ash by type of boiler and method of firing, percent (35)

Boiler and/or type of firing	Coarse	Fly
Wet bottom: Front, opposed, and tangential firing[1].....	35	65
Dry bottom: Front, opposed, and tangential firing[1].....	15	85
Cyclone.....................	[2]90	10
Spreader stoker.............	35	65

[1]Pulverized coal.
[2]Other data indicate lower figure. TVA Paradise plant produces 65 pct coarse ash (75).

NOTE.--Wet bottom ash is called boiler slag.

TABLE 2. - Approximate amounts of accumulated anthracite coal wastes

Waste type	10^6 yd^3	Portion of total, pct[1]
Breaker refuse.........	390	45
Mixture................	220	25
Breaker refuse and silt	140	16
Mine refuse............	100	11
Silt...................	23	3
Tunnel rock............	2	<1
Total............	875	100

[1]Rounded.

Much of the coal ash can be beneficiated by magnetic separation. Typical wet and dry low-intensity magnetic separation results (18) are shown in table 3. Liberation of other minerals has been noted also in studies on beneficiation or fractionation of coal ash (3, 8-9, 37-39, 44-45, 47, 49, 66-67, 78, 80, 86, 98).

Coal shale includes wastes, such as breaker waste, silt, tunnel rock, and mine waste, obtained in mining and processing coal. The major alumina-containing minerals are illite, montmorillonite, and kaolinite. Coal shale comes in a variety of sizes and has great differences in coal content or heating

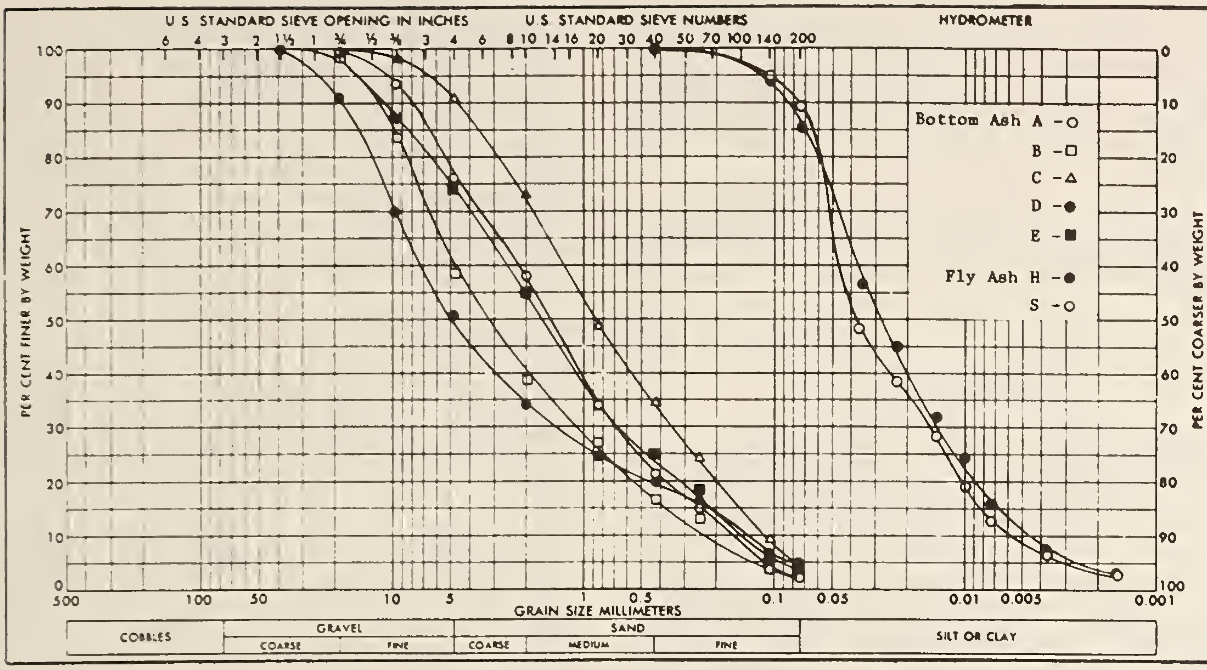

FIGURE 1. - Grain size distribution curves for bottom ash and fly ash (69).

TABLE 3. - Composition of fly ash and fractions obtained by magnetic separation (18)

Constituent	Whole fly ash, 100 parts	Chemical composition, pct			
		Dry separation		Wet separation	
		Magnetic, 23.6 parts	Nonmagnetic, 76.4 parts	Magnetic, 26.1 parts	Nonmagnetic, 68.4 parts
SiO_2.........	42.36	20.31	47.89	20.83	53.0
Al_2O_3........	17.91	10.21	20.04	9.95	22.83
[1]Fe_2O_3.......	19.29	60.08	6.56	65.00	5.24
CaO..........	4.49	1.87	4.88	1.32	5.82
MgO..........	.72	.40	.76	.42	.99
Na_2O.........	.35	.18	.35	.14	.31
K_2O..........	1.72	.81	1.85	.71	1.91
SO_3..........	2.13	.79	2.04	ND	ND
LOD..........	.58	.13	.45	.12	.56
LOI..........	10.39	10.39	12.40	1.70	8.46

LOD Loss on drying at 110° C.
LOI Loss on ignition from 110° to 800° C.
ND Not detected.
[1]Total iron reported as Fe_2O_3.

value. More mine and process wastes are generated from underground mining than from surface mining. Underground wastes have higher heating values and, when accumulated, combustion is a greater hazard. The danger of combustion is an overriding incentive for some type of treatment of high-coal-content coal shale.

Since many alumina extraction processes require preliminary calcination, there is an added incentive for use of high heating value process plant or mine wastes. Process plant and mine wastes also can be contaminated with varying amounts of calcareous or siliceous bedding rocks and pyrite and are not the same composition as the ash produced from the mined coal. However, the alumina, alkali, and alkaline earth content of process and mine wastes can generally be predicted from the ash analyses, i.e., if it is high in one it is high in the other and vice

versa. Pyrite and other sulfides produce acid solutions in accumulated wastes and can result in more serious metal pollution than that occurring from coal ash.

In order to evaluate technologies for extracting alumina from U.S. coal waste, available data on mineralogical composition, chemical composition, and physical properties of the wastes should be analyzed as thoroughly as possible because the characteristics of the individual coal waste influence the type of alumina extraction process that can be used and the overall process economics.

CATALOG OF PERTINENT LITERATURE

BIBLIOGRAPHIES

Bibilographies that include references to coal composition, bedding materials, coal mine and process plant wastes, and coal ashes are available (2, 19-22, 24, 97). Annotated bibliographies include Condry (21), "Recovery of Alumina From Coal Refuse," on alumina recovery methods and Akers (2), "Coal Minerals Bibliography," on minerals associated with coal. For coal ash production and utilization, an excellent annotated bibliography is included in Cockrell (20), "New or Undeveloped Methods of Producing and Utilizing Coal Ash." The work covers the period before 1968. Coalgate (19), "Literature Survey--Coal Associated Wastes," covers the period 1900 to 1972. Deurbrouk (22), "Bureau of Mines Publications on Coal Preparation (1910-60)," and reference 97, "U.S. Government Publications on Coal Preparation 1960-1981," include most government publications on coal preparation and beneficiation.

Eisele (24), "Evaluation of Technology for Recovery of Metallurgical-Grade Alumina From Coal Ash," lists a number of of recent publications on alumina recovery techniques.

CHARACTERIZATION OF COAL WASTES AND ASHES

Chemical composition and physical characteristics of coal wastes (25-34, 54) and ashes are covered in a number of studies (1-2, 6-7, 9-11, 13-18, 23, 43-45, 48, 55, 58, 68, 79, 82-91, 95). The most comprehensive listing of chemical compositions of coal ashes are in Abernathy (1), "Major Ash Constituents in U.S. Coals," and for coal waste materials in Buttermore (16), "Characterization of Coal Refuse."

Excellent chemical data for lignite are in five papers by Manz (61-65) and in two papers by Sondreal (84-85). Reference 85, "Characteristics and Variabilities of Lignite Ash From the Northern Great Plains," is especially valuable.

For anthracite waste materials, MacCartney (55), "Pennsylvania Anthracite Refuse," is a good source. Rose (75), "Composition and Property of Kentucky Fly Ashes," gives excellent data for east Kentucky (Appalachian bituminous) and west Kentucky (east central bituminous) coal ashes.

Chemical analyses of coal silt and gob refuse are given by Buttermore (16) for several regions. Backer (7), "Properties of Western Coal Waste Materials," gives analyses for Utah and other western coals. Busch (15), "Physical Property Data on Fine Coal Refuse," gives analyses for Appalachian coals. Wewerka (99) gives analyses for fine waste materials from Illinois Basin cleaning plants. A recent compilation by Torry (94) covers trace contaminants in coal.

No comprehensive compilation of the physical properties of coal process plant and mine wastes was found. There are many important regional papers and some papers limited to specific types of waste. Buttermore (16) gives data for Appalachian bituminous, Interior

Province[4] bituminous and Rocky Mountain Province coals, MacCartney (55) gives data for the Pennsylvania anthracite region, Backer (7) covers western coals, while Busch (14-15) gives physical property data for coarse and fine wastes from the Eastern region. Bradley (13), "Characterization of Solid Constituents in Blackwater Effluents From Coal Preparation Plants," gives data on washer wastes from the Appalachian region. Majdidzedeh (59), in a report on a laboratory investigation, discusses material characteristics of powerplant bottom ashes and describes their performance in bituminous mixtures for road paving. Moulten (69) covers bottom ash and boiler slag characterization of bottom ash. Numerous authors give data on fly ash, but the papers that provide considerable information include Rose (75), Hulet (44), Fowler (36), Hurst (45), and Ray (72). Manz (61) gives data for lignite fly ash.

Chemical composition and physical characterization are discussed in several papers on the beneficiation of wastes: Styron (90), "Quality Control and Beneficiation of Fly Ash," Stirling (89), "Beneficiation of Fly Ash," and Aldrich (3). Rosner (76-77) gives chemical and physical data for several western utility plant ashes. Additional physical and chemical data on the extraction of alumina from coal ashes are discussed by Hsieh (43), Chou (18), and Ripley (73-74).

LOCATION AND PRODUCTION OF COAL WASTES AND ASHES

Data on location and production of coal wastes and ashes are given in (6-7, 10-12, 17, 29-34, 55-65, 70-71, 81, 84-88, 91, 93, 95, 97). Detailed data on the cost of coal refuse disposal are given in Bureau of Mines IC 8576 (95). The best source on production and utilization of coal from which waste production data may be inferred is the 1981 "Keystone Coal Industries Manual" (56). Data on coal resources, production, consumption, and end-use forecasts are updated annually. Nameplate data in the Department of Energy (96) inventory of powerplants, which lists powerplants in the United States with output rating and type of fuel used, are updated annually. Tolle (92) gives ash production by region and State for 1980, based on preliminary data of the National Ash Association.

Many papers have been published in the proceedings of the six fly ash symposia (30-34, 42). Important papers on northern Great Plains coals and wastes are published in the proceedings of the symposia on the technology and use of lignite (25-27, 40, 50-52). Overviews by Brackett (10-12) and Faber (28-29) are of interest. The papers of Manz (61-65) and Sondreal (84-85) cover the northern Great Plains lignite area.

Locations and size of burning and burnt waste banks are given by Stahl (87) and McNay (57). MacCartney (55) is the best source for the Pennsylvania anthracite region.

Many books on coal preparation and production have been published. Recent works of value include Leonard (53), "Coal Preparation," Schmidt (79), Coal in America," and Torrey (93), "Coal Ash Utilization."

CATEGORIZATION OF COAL WASTES

There are many different types of coal wastes that are being or have been produced in the United States. In order to evaluate processes for the extraction of alumina from coal wastes, the types of wastes must be classified. Two cross indexes developed to define the type of coal waste are as follows:

[4]Province nomenclature common to the U.S. coal industry is given by T. R. Scallon in "An Assessment of Coal Resources," Chem. Eng. Prog., v. 73, No. 6, June 1977, pp. 25-30.

I. Method of waste generation and coal content usable as fuel.

1. Process plant waste, high heating value (>4,000 Btu/lb).

2. Process plant waste, low heating value (<4,000 Btu/lb).

3. Process plant waste, no heating value.

4. Mine rock and trommel waste, no heating value.

5. Burned refuse, no heating value.

6. Process ash, no heating value. (From coal processes, such as synthetic production or fluosolids burning. Process temperatures are usually low.)

7. Low temperature utility ash, no heating value. (Coal product burned at about 1,000° C.)

8. High temperature utility ash, no heating value. (Coal product burned at about 1,500° C. Category includes fly ash, bottom ash, and boiler slag.)

II. Location,[5] type of coal,[6] and alkaline earth content.

a. Eastern Pennsylvania anthracite.

b. East and central bituminous, low calcium (<4 pct).

c. East and central bituminous, high calcium (>4 pct).

d. West and south central lignite, low calcium (<4 pct). (Mainly in Rocky Mountain region.)

e. West and south central lignite, high calcium (>4 pct). (Predominant material in Rocky Mountians, Pacific Coast and Gulf lignite provinces.)

f. West and south central lignite, high calcium and magnesium (>4 pct). (Includes subbituminous coals of the Powder River basin of Montana and Wyoming and lignites of the Fort Union Formation of the northern Great Plains.)

By combining these two sets of indexes, 48 categories of coal waste result, which can be denoted 1a, 1b, etc. Figure 2 indicates which of the categories provide major percentages of current coal waste production or existing coal waste accumulations. Examples of chemical compositions or ranges of chemical compositions for different fly ashes of categories 8b, 7c, 8c, 8d, and 8e; for different bottom ashes of categories 6a, 8b, 7c, 8c, and 8e; and for different types of coal mining and process wastes (coal shale) of categories 1a, 2a, 1b, 2b, 3b, 2c, 1e, 2e, and 1f, are presented in table 4.

Many of these 48 categories shown in figure 2 can be grouped together according to their utilization for alumina extraction. The members of any group are compatible as feed to an alumina extraction plant. These groups are

1a, 1b - Combined because of similar composition. Because of proximity to population centers in eastern Pennsylvania untreated 1a material presents greater health and enviromental hazards than it would in other areas.

1d, 1e, 1f - Combined because there is much less of 1d and 1f. These materials are mainly from underground mines in Utah and Colorado, and any process should handle all types.

2a, 2b - See 1a, 1b group.

2d, 2e - Combined because there is much less 2d, which would be combined with 2e for large-scale exploitation. Any

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[5]West and south central refers to coals from the northern Great Plains, Pacific Coast and Gulf Provinces.

[6]Western bituminous and subbituminous coals are classified in this report as lignites because their ash is most accurately described as lignite type ash.

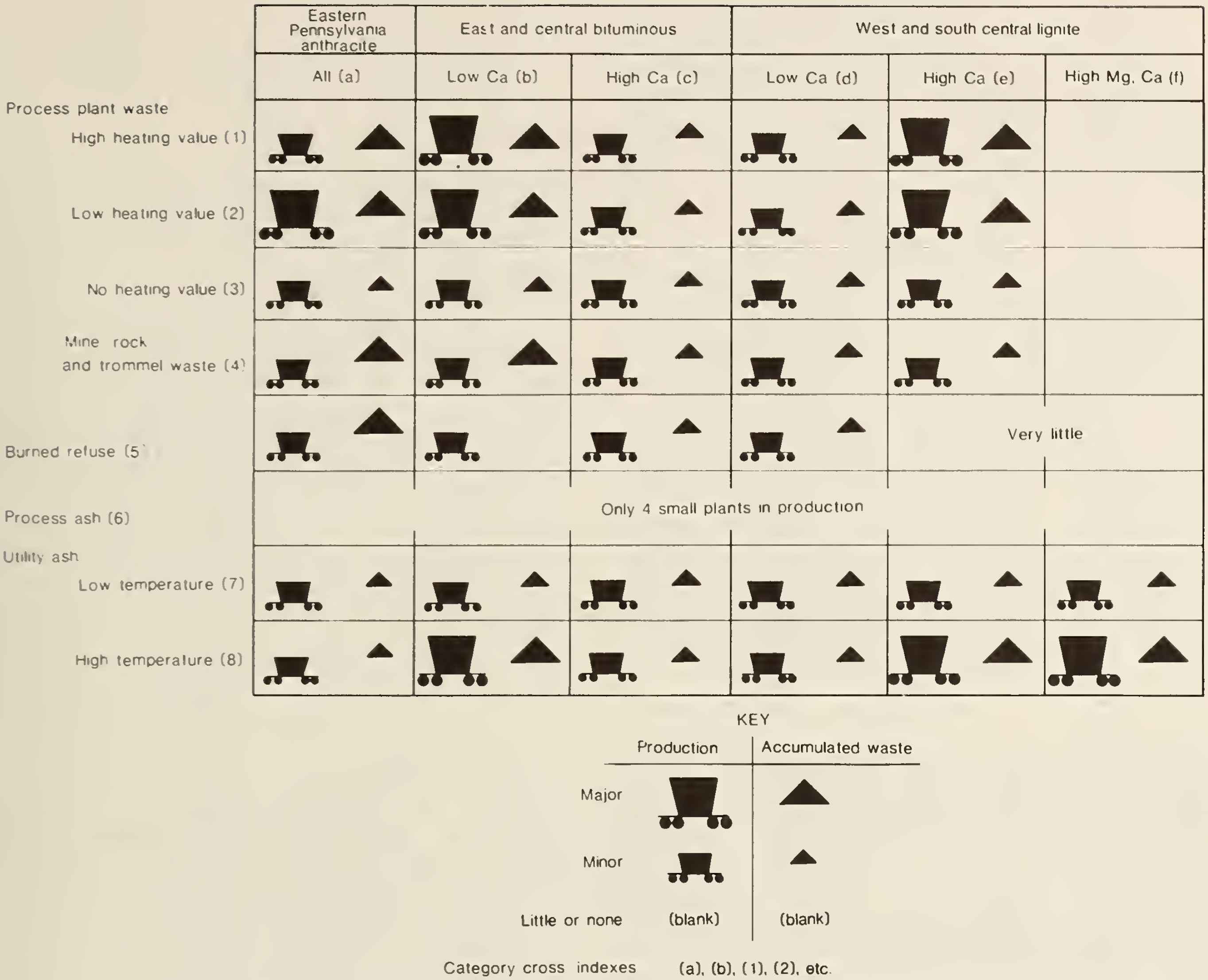

FIGURE 2. - Production and accumulation of U.S. coal waste by category.

composite of 2d and 2e would be classified as a high-calcium category.

3a, 3b, 4a, 4b - Combined because of similar composition except for size difference.

3c, 4c - See 3a, 3b, 4a, 4b group.

3d, 3e, 4d, 4e - Combined because of similar composition except for calcium content and size differences, and because high- and low-calcium materials are closely associated and could be combined and yield a high-calcium composite.

3f, 4f - See 3a, 3b, 4a, 4b group.

5a, 5b - Combined because of similar composition.

5d, 5e, 5f - Eliminated because there is insignificant tonnage, widely scattered, and inaccessible.

6a, 6b, 6d, 6f - Combined because tonnage otherwise is insignificant.

7a, 7b - See 5a, 5b group.

8a, 8b - See 5a, 5b group.

TABLE 4. - Examples of chemical compositions or ranges of composition of fly ashes, bottom ashes, and coal mining and processing wastes, by category,[1] percent

Component	Fly ash							Bottom ash				
	8b[2]	7c[2]	8c[2]	8d[3]	8e[4,5]	8e[4]	8e[6]	6a[7]	8b[2]	7c[2]	8c[2]	8e[6]
LOI	1 - 9	43	1 - 9	NA	0.5	0.5	1	NA	1 - 33	19	0.2- 6	1
Moisture	.1 - .3	.1	.1 - .2	NA	.5	.5	.5	NA	.1- 1.1	.6	.1- .3	.5
Ash	94 -99	57	91 -99	NA	NA	NA	NA	NA	67 -100	81	94 -100	NA
SiO_2	39 -55	53	39 -48	56	49 -60	43	66	52 -58	34 - 53	50	36 - 42	71
Al_2O_3	17 -30	21	17 -20	28	14 -19	18	16	22 -25	15 - 25	21	15 - 16	12
Fe_2O_3	9 -32	12	19 -32	4	3 - 6	3	4	2	15 - 38	20	23 - 38	.4
TiO_2	1 - 2	1	1	1	NA	NA	2	2	1	1	1	2
CaO	1 - 3	6	4 - 9	4	6 -25	21	7	4 - 8	1 - 4	4	4 - 13	6
MgO	1	1	1	1	1 - 2	1.5	2	1	.1- 1.2	1	1	2
K_2O	2 - 3	2	2 - 3	1	[8].5- 1.5	[8]0.5- 1.5	.4	3	2 - 3	2	2	.3
Na_2O	.2 - .6	.3	.3 - .6	2	[8]NA	[8]NA	.5	.3- .4	.2- .5	.3	.4- .5	.5
SO_3	.2 - 2.5	1.6	.9 - 2.3	2	1 - 6	1.6	.1	.4- 1.7	.3- 11	2	1 - 19	.4

Component	Coal mining and processing waste								
	1a[9]	2a[9]	1b[10]	2b[10]	3b[10]	2c[11]	1e[12]	2e[12]	1f[12]
Volatile[13]	NA	NA	22	16	7	15 -20	23	16	29 - 32
Moisture[13]	7	4 - 9	35 -55	7	7	1 - 2	NA	0	NA
Ash[13]	54	65 -82	25 -32	55	90	68 -75	49	74	27 - 39
C[13]	39	12 -27	46 -52	29	3	14 -18	37	17	47 - 58
S[13]	.2	.3	1	1	1.5	3 -14	4	.2	.6- .9
[14]SiO_2	56	56 -63	53 -57	59	61	36 -55	64	63	51 - 56
[14]Al_2O_3	27	19 -23	25 -27	23	23	11 -20	14	23	21 - 22
[14]Fe_2O_3	2	2 - 5	5 - 8	7	8	10 -24	12	4	5 - 6
[14]TiO_2	4	2 - 3	1	1	1	1	1	1	1
[14]CaO	.03	.03- .13	1 - 3	2	1	6 -10	3	4	8 - 14
[14]MgO	.5	.5 - .6	1 - 2	1	1	1 - 3	1	2	1 - 2
[14]K_2O	2	3 - 5	4	4	4	1 - 3	3	2	2 - 3
[14]Na_2O	.2	.2 - .5	.2- .5	.4	.3	.1- .6	.2	.8	1 - 2
[14]SO_3	1	1	1 - 3	2	.7	NA	1	.2	1 - 3

LOI Loss on ignition. NA Not available.

[1]Number and letter refer to cross-index coding used in figure 2.
[2]Reference 75, table 5 or 6.
[3]Data supplied by D. Karner, Arizona Pub. Service Co., Phoenix, AZ.
[4]Reference 76, table 1.
[5]Reference 77, table 2.
[6]Data supplied by M. Wadlington, Texas Utilities, Dallas, TX.
[7]An ash made by fluosolids combustion of anthracite culm (43, table 1).
[8]Total alkali (pct Na_2O + 0.658 × pct K_2O) given in place of pct Na_2O.
[9]Reference 4.
[10]Reference 15, table 4 or 5.
[11]Reference 16, pp. 16-17.
[12]Reference 7, table 8 or 9.
[13]Analyses of waste material.
[14]Analyses of ash formed by combustion of waste material.

REVIEW OF COAL WASTE DESCRIPTIVE LITERATURE

EASTERN PENNSYLVANIA ANTHRACITE

General

Anthracite is coal containing more than 92 pct fixed carbon (56) and is limited to four fields of eastern Pennsylvania. Originally, anthracite waste was separated into breaker refuse, silt, mine refuse, tunnel rock, and mixtures of these materials. Banks accumulated before 1900 have yielded up to 75 pct coal, but coal content of subsequent production banks decreased until, at present, coarse process waste, breaker refuse, mine refuse, and tunnel rock, seldom contain more than 5 pct commercially salable coal (55). Silt produced can contain enough coal to be considered high heating value. The carbon-free ash has the following approximate analyses[7] (86) in percent: SiO_2, 50-75; Al_2O_3, 30-37; Fe_2O_3, 3-10; TiO_2, 1-2; CaO, 1-2; MgO, 0-1; K_2O and Na_2O, 1-3; and SO_3, 0-1.

Heating values were determined for six waste banks sampled and used in a feasibility study on production of steam and alumina (4). The samples have heating values between 1,000 and 5,000 Btu/lb and can be burned in fluidized-bed combustors. About 4,000 Btu/lb is the heating value of waste used in an Alcoa study on alumina extraction (43). At present, some of the silt material is being processed to decrease ash, shipped to Korea, briquetted, and used as a 30-pct ash fuel (56).

Anthracite process wastes are situated closer to highly populated areas than other coal wastes and are often unstable. They are very inflammable owing to their high coal content, especially the finer sized material, and contain appreciable quantities of leachable objectionable compounds, mostly sulfides. In the past, accummulated anthracite wastes have produced the most serious enviromental problems of any type of coal waste and represent the greatest ongoing hazard (55, 57, 87).

[7] Metal analyses throughout the report are given for an oxide form. This is consistent with industrial usage and does not necessarily indicate the actual chemical form.

Production

The amount of waste presently produced by process plants is very small compared with past production. Present anthracite coal production, including waste banks for fuel, is less than 5 million tpy, compared with 100 million tpy in 1917 (56, 86). Only 600,000 tpy of present anthracite production is from underground mines. Of 250,000 tons of new waste production per year, 15,000 tpy is the silt type that has high heating value. Current production of anthracite ash is several hundred thousand tons per year.

Storage

Anthracite waste has been accumulated (55) in about 800 banks covering 12,000 acres and totals about 900 million yd^3. Much of this material has burned or is burning. Breaker refuse is the major component, much of which is in banks mixed with tunnel rock, mine refuse, and silt. Approximate amounts of these anthracite waste products are shown in table 2.

EAST AND CENTRAL BITUMINOUS, LOW CALCIUM

General

This material, which has a relatively high alumina and low alkali and alkaline earth content (<4 pct CaO), constitutes the principal coal waste produced in the Eastern United States and the central United States. Coal between anthracite and lignite is referred to as bituminous. It is estimated that 25 pct of the coal from underground mines is process plant waste and 10 pct of that is fines or silt (7, 11, 13, 63). The silt contains about 4,000 Btu/lb (14-15) but the coarse material is usually significantly less.

Alumina in the ash analysis of the coal is between 20 and 30 pct and the waste products are expected to contain slightly less (1). Waste banks are easily inflammable but are not located as close to urban centers as are anthracite waste banks (55, 57-58, 87). As with the anthracite, many of the waste dumps are serious health and pollution hazards owing to leaching of objectionable compounds, and must be made innocuous. Other banks forming ponds are sometimes unstable and can fail, causing flooding. Disposal costs (1973) for coal waste dump reclamation ranged from $1,800 to $15,000 per acre in Pennsylvania (88). These costs could be credited partially or wholly to any process utilizing the waste. As far as alumina extraction is concerned, these wastes (eastern and central bituminous) can be regarded as nearly identical to their counterparts from eastern Pennsylvania anthracite. Alumina content in the anthracite waste averages several percent higher than in the bituminous waste.

The Hat Creek coal of British Columbia has an ash similar to east and central bituminous. The Hat Creek coal ash has been extensively tested for alumina extraction (73-74).

Production

Production data, mainly from underground mines in the Appalachian area (56), indicate that more than 60 million tons of coarse and 6 million tons of fine refuse are produced annually. A large, but indeterminant, number of burnt banks exist. In 1964, 422 of 495 burning spoil banks in the United States were in the Appalachain bituminous area (87). The number of burning banks has decreased because some bank fires have been extinguished and disposal methods have improved; 300 banks were burning in 1978 (99).

An estimated 25 million tons of utility ash is produced annually, mostly high temperature ash from pulverized coal. This figure is derived from coal consumption figures in the 1981 Keystone Coal Industries Manual (56). Many older plants in the region have stoker-type burners. Since these plants are relatively small, the amount of ash produced is not significant, and since much of this ash is used in the building trade, it can not be considered an important source of alumina. Coarse ash or slag is usually used in building materials. Some cyclone-fired plants produce a significant amount of high-temperature boiler slag.

Storage

Although not well documented, a very large amount of process plant waste and burned waste exists in the eastern and central bituminous area. The amount undoubtedly is many times greater than the 1 billion tons mentioned for anthracite waste.

The large ash production would indicate that a considerable quantity has accumulated. A high percentage of the ash is being utilized.

EAST AND CENTRAL BITUMINOUS, HIGH CALCIUM

General

Except for the high calcium content (>4 pct calcium) this material is similar to the low-calcium east and central bituminous waste (1). The high-calcium bituminous coals occur in the eastern interior region, the western interior region, and in scattered occurrences in the Appalachian regions. Coal with high-calcium ash has been found in five seams in Virginia (1) and in some West Virginia deposits (16). The material has higher iron and alumina contents than the lignite-type coal ash (1). In general, the percentage of Fe_2O_3 exceeds the sum of the percentage of CaO and MgO. Bituminous coal ash in which the percentage of CaO and MgO exceed the percentage of Fe_2O_3 is termed lignite-type ash. This type of material occurs in the west and south central areas of the United States.

Production

A smaller fraction of the high-calcium bituminous material is mined underground than low-calcium bituminous material and, therefore, proportionally less of the higher-heating-value process plant waste is produced from this material than from low-calcium bituminous.

No reliable data were found to differentiate between production of high- and low-calcium process plant wastes from bituminous coals or production of high-and low-calcium utility ash from bituminous coals. Two Kentucky utility plants produce about 400,000 tons of fly ash, 70,000 tons of bottom ash, and 50,000 tons of boiler slag per year. Average ash contents of the coal burned in the plants are 10 and 4.5 pct (75).

Storage

Available information on accumulations of bituminous wastes does not distinguish between high and low calcium, except that there is far more low-calcium material. Since coal wastes fires occur, a significant fraction of burnt refuse exists.

WEST AND SOUTH CENTRAL LIGNITE, LOW CALCIUM

General

Consolidated coal having less than 8,300 Btu/lb heating value is commonly referred to as lignite. Lignite-type ash is ash in which the sum of the percentage of CaO and MgO exceeds the percentage of Fe_2O_3 (84). Only rarely does the ash from lignite or bituminous coals of the west and south central area fail to meet this "lignite-type" specification. Less of the low-calcium lignite ash has been produced than either the high-calcium or high-calcium, high-magnesium ash.

Production

A significant tonnage of coal that has lignite-type ash of low calcium and magnesium content is being mined in the Rocky Mountain region (1). Since the lignite is strip mined and used as "run-of-mine" product, the amount of process plant and mine waste is nonexistent and would contain little or no heating value. The Four Corners Power Plant in New Mexico produces more than 1 million tons of utility ash per year.

Storage

Little information is available on accumulations of this material. Process plant wastes and mine wastes would be small and widely scattered.

WEST AND SOUTH CENTRAL LIGNITE, HIGH CALCIUM

General

This type of material predominates in the Rocky Mountains, the Pacific Coast and the Gulf lignite provinces (1, 56), but not in the Great Plains area. Although little analytical data on Texas coal were found, the material is being mined from the Wilcox Formation and has high calcium and low magnesium (available analyses provided by D. Taylor of Texas Utilities Co., and reference 62). Ash from the high-calcium lignite has alumina contents that range from 10 to 25 pct. Iron content can vary from 5 to 14 pct and SiO_2 from 20 to 50 pct.

Most ash is produced by utilities using pulverized coal in their burners. The lignites contain about 20 pct bottom ash. The lignite fly ashes are coarser than those from bituminous or anthracite coals. Some utility ash from Alberta, Canada, coals have high-calcium, low-magnesium type ash (74).

Production

Large quantities of coal with high-calcium, lignite-type ash are being mined and greater production is anticipated (23). There are underground mines and standard coal cleaning plants only in Colorado and Utah (7). The amount of process plant and mine waste produced is small and scattered, especially when compared with bituminous coal waste.

Utility ash from high-calcium lignites is produced in very large tonnages because most of the lignite used by utilities is burned in very large, pulverized coal fired plants in the West and Southwest. Lignite powerplants are larger than those using bituminous or anthracite coal.

Storage

Process plant wastes are widely scattered and do not provide the environmental problems associated with eastern banks. Some of the waste banks have burned. Eighteen were burning in 1964 and 20 in 1971 (57, 87). Large quantities of ash are being stored and the amounts are increasing (7, 56).

WEST AND SOUTH CENTRAL LIGNITE, HIGH CALCIUM AND HIGH MAGNESIUM

General

Lignite coals with high magnesium content occur in the northern Great Plains and comprise 25 pct of the U.S. coal reserves (85). Great variations are found in the ash analyses of the coals even within a single mine. Alumina content is low and ranges from 10 to 25 pct. Although most ash production is from pulverized coal fired plants, some plants are using cyclone furnaces and some stoker spreaders are in operation. Cyclone furnace production of bottom ash has been reported at both 65 and 90 pct, spreader stokers at 35 pct, and pulverized coal burners at 15 pct (table 1).

For the purposes of this study, the subbituminous coals of the Powder River basin of Montana and Wyoming are classified with the high-calcium, high-magnesium lignites.

The coals of Saskatchewan are an extension of the Fort Union Formation of the northern Great Plains province and have high-magnesium, high-calcium ash (100).

Production

Because little or none of the type of material is mined underground, mine waste, process plant waste, and burned refuse are nonexistent. Utility ash production is very large but less than that for the high-calcium, low-magnesium lignite. Large quantities are produced from pulverized coal and cyclone furnace utilities in Minnesota and North Dakota.

Disposal

Accumulated wastes are limited to utility ash and the amounts are increasing.

SUMMARY AND CONCLUSIONS

Coal shale and coal ash in the United States vary widely in accumulated volume, production rate, chemical composition, and physical characteristics. Nevertheless, it was possible to classify these wastes on a basis of geography, residual heating values, temperature of processing, type of prior processing, and alkaline earth content. The coal waste categories from this classification vary in many factors that affect their possible utilization as a source of alumina. Some categories can be grouped together on a basis of compatability as feed to alumina extraction processes.

The data in this report indicate that anthracite culm provides the most attractive source of alumina from coal shale for the following reasons:

1. Large quantities are easily accessible.

2. Its continued storage constitutes a severe enviromental pollution and combustion hazard problem. Utilization should provide more substantial, though not presently established, commercial incentives than other coal wastes.

3. Anthracite culm is unsuitable as a building material as opposed to coal ashes, which have some potential in this regard.

4. Many anthracite culms contain sufficient coal for the calcination step of several attractive alumina extraction processes or for physical beneficiation as a valuable byproduct.

5. It generally has higher alumina content than other coal ashes and coal shale except for the eastern bituminous areas.

6. It has a relatively low content of impurities deleterious to the alumina extraction processes.

Bituminous wastes stored in the Appalachian region are similar in quantity and composition to the anthracite culm but are less attractive because of their scattered location in relatively isolated areas.

Although some coal ashes in the eastern United States have alumina contents approaching those of anthracite culm or eastern bituminous coal shale, many of these eastern coal ashes are being partially or completely utilized for building material (5, 46). Western coal ashes, which are much less utilized for building material, are much lower in alumina.

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